

DEPARTMENT OF AGRICULTURE, CONSERVATION AND FORESTRY

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Table of Contents

1. Metallic Mineral Deposits in Maine	1
2. Why Are Sulfide Minerals of Great Concern?	1
3. Components of a Typical Metallic Mineral Mine	2
A. Mineral Extraction Site	3
B. Ore Concentrating Facilities.....	4
C. Mine Wastes.....	6
D. Water Treatment.....	8
4. Current and Past Metallic Mining Activity in Maine	10
5. Legacy Mines vs. Modern Mines	11
6. Surface Mining vs. Underground Mining.....	13
7. Mine Reclamation.....	13

Overview of Maine Metallic Mineral Deposits and Mining

Robert G. Marvinney, Maine State Geologist

1. Metallic Mineral Deposits in Maine

Maine’s complex geology hosts numerous metallic mineral deposits, mostly associated with two broad belts of volcanic rocks and numerous granite intrusions (see [Metallic Mineral Deposits of Maine map](#)).

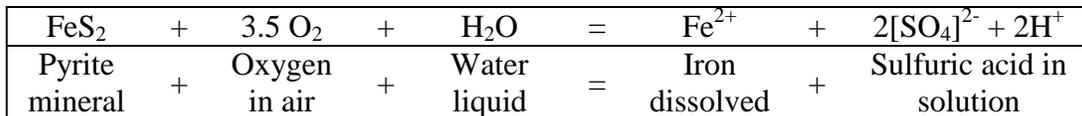
Notes to accompany the map:

- This is a map of mineral **occurrences**, not of future mines. Most occurrences shown on the map are of insufficient size to warrant further investigations.
- A few of the larger deposits have been characterized to some degree. None has been sufficiently characterized to determine whether or not it might be mined economically.
- Page 2 of the map lists Significant Known Metallic Mineral Deposits in Maine, including approximate tonnage and grade. Essential geologic details of size, shape, and grade would be determined by exploration and advanced exploration at each site.
- Most occurrences on the map are base metal (iron, copper, lead, zinc) sulfide deposits, some with precious metals (gold, silver).
- Some of the known deposits are oxide deposits, such as the Maple-Hovey mangiferous slates in Aroostook County.
- Maine shares much geology in common with New Brunswick. As has happened in New Brunswick, a comprehensive exploration program would lead to additional discoveries in Maine.

2. Why Are Sulfide Minerals of Great Concern?

- Sulfide minerals are compounds of sulfur with metals such as iron, copper, lead, or zinc.
- Upon exposure to the atmosphere and water, sulfide minerals weather, releasing metals and sulfuric acid. Both oxygen and water are necessary for reaction to occur.

For example:



- Other metals present in the minerals, such as arsenic, also go into solution.
- The grinding necessary to separate mineral components greatly increases surface area, accelerating the weathering process.
- Pyrite is one of the most common minerals in mine tailings. It has little economic value.

3. Components of a Typical Metallic Mineral Mine

A typical metallic mineral mine consists of a mineral extraction site which may be an open-pit mine or an underground mine. Ore extracted from the mine is sent through a mill complex where the minerals are crushed and separated. Waste minerals are usually managed at the mine site. The ore concentrate is sent off site for smelting to produce pure metal. The accompanying figure shows an example of how the various components could be arranged at a mine site. Details of the site design, specific to each mine, depend on many factors.



Components of a mine. Aerial view, showing ore extraction sites (pits), processing area (crusher, concentrator), waste storage areas (tailings and main waste), stockpiles, and water management facilities. This example is of a large open pit mine. (*Red Dog Mine, Alaska*)

A. Mineral Extraction Site

Open pit. This method of mining accesses the ore from the surface through a series of benches that allow vehicle access. This is the easiest method of mining, but it generates far more waste rock than does underground mining.



Photo: F.M. Beck, Inc.

Small open pit, Callahan Mine, Maine, 1972. The pit was 360 feet deep, about 500 feet across. 800,000 tons of ore were mined from this site from 1968-1972.

Open Pit Mining

- Ore accessed on surface
- Blasting
- Haul to crusher/mill



21

Source: U.S. EPA

Large open pit, Bingham Canyon Mine, Utah. The Bingham Canyon pit is the largest man-made excavation on earth, measuring more than 2.5 miles across and over 3,000 feet deep. This ore body measures 832 million tons, over 1,000 times larger than the Callahan deposit.

Underground workings. Deeper deposits are often mined using underground mining methods. While perhaps more expensive to operate, underground mining is more selective and results in far less waste rock than does surface mining, so environmental management costs may be less.

B. Ore Concentrating Facilities

The minerals of interest in an ore deposit may comprise 1% or less of the ore in low grade deposits, and up to 15-20% in the case of the richest deposits. Regardless of the grade of the ore, a large volume of uneconomical minerals must be separated from the valuable minerals through a combination of mechanical and chemical processes.

Rock crushers. A series of rotating ball mills and grinders mechanically reduce the size of the ore rock to a very fine particle size.

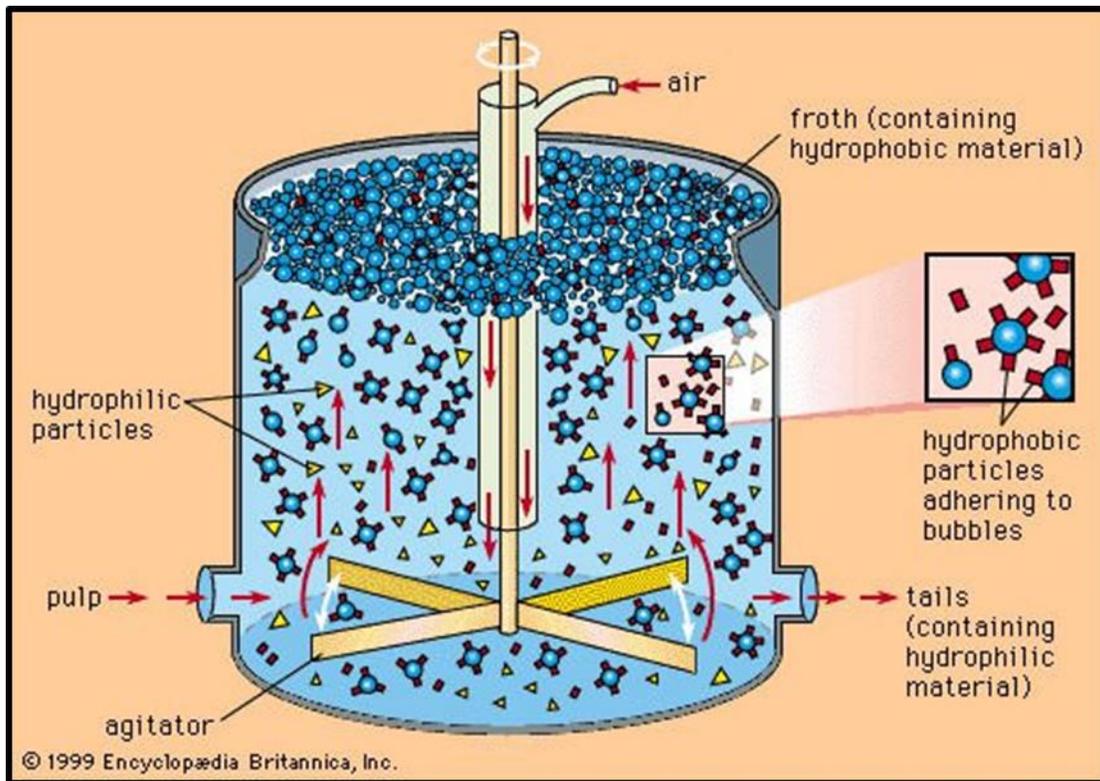
A series of mills with successively smaller steel balls reduce the grain size such that each grain is of a single mineral – this often requires grinding to a fine powder depending on the natural properties of the ore.

Water may be added during this process to facilitate the next phase in ore concentrating.



Source: U.S. EPA

Rotating ball mill. Used for grinding ore to a fine particle size.



Flotation cell. The pulp of ground ore and water is introduced to the cell along with chemicals. Air is injected into the cell to create bubbles and an agitator mixes the pulp. The ore minerals adhere to the bubbles and float to the top as a froth, which is scraped off. Unwanted minerals sink to the bottom of the cell as ‘tailings.’

Concentrators. After grinding, the ore minerals must be separated from the uneconomical minerals. A physical way of concentrating the ore minerals is through a series of flotation cells, illustrated in this diagram.

- The ore concentrate is dried and shipped to a smelter for final processing.
- Tailings are eventually stored on site in a tailings storage facility.
- Chemicals used for concentrating may include organic compounds, cyanide, copper sulfate, zinc sulfate, oils, alcohol, lime, acids or other chemicals, depending on the ore composition.
- Management of tailings and appropriate handling of chemicals are major environmental concerns at a mine site.

Leaching. Alternatively, metals may be extracted from the crushed and ground ore by leaching with chemicals. Gold ore is often processed this way by leaching with cyanide. While this process was often done in an open environment (heap leaching), it is now more commonly done in a closed environment (vat leaching). Heap leaching is prohibited in Maine by law.

C. Mine Wastes

Among the greatest environmental concerns at a mine site are the mine wastes, which occur in two forms, waste rock and tailings.

Waste rock. In many mines, considerable rock must be removed to access the ore.

- While uneconomical to mill, this waste rock often contains enough sulfide minerals to generate acid on exposure to the atmosphere.
- The surface area is increased through the mining process, thereby increasing exposure of minerals to the atmosphere.
- Open pit mines generate much more waste rock than do underground mines.
- Management techniques include separating non-acid-generating rocks from acid-generating rocks, and capping the waste or backfilling waste rock into the open pit or underground workings.



Photo: Robert Marvinney

Waste rock pile. Large slab in right foreground is 3 feet across. (*Restigouche Mine, northern New Brunswick.*)

Tailings. Tailings are the most significant environmental concern at any mine site. Reasons for this concern include:

- A large volume of crushed ore sent through the mill ends up as tailings. For example, the average grade of copper ore being mined in the world is about 1%, meaning that 99% of the material sent through the mill ends up as tailings.
- Fine crushing in the mill increases the surface area of the minerals exponentially, allowing more opportunity for chemical reaction with water and oxygen, which means more opportunity for sulfide minerals to generate acid.

- Several recent, high-profile tailings dam failures underscore the need to ensure that these facilities are designed and built to high standards.



Tailings facility, Brunswick No. 12 Mine, northeastern New Brunswick. The mine began operating in 1964. When operating, Brunswick No. 12 was the largest underground zinc mine in the world. The tailings impoundment, holding about 100 million tons of waste (mostly pyrite), covers 1.3 square miles. A water treatment plant to the right of the ponds must operate in perpetuity. The long axis of the tailings basin measures 6,500 feet.

Isolating residual sulfide minerals from water or oxygen (or both) inhibits acid-generating chemical reactions. Some methods used to address environmental concerns from tailings:

- Install underliners to prevent infiltration of leachate into groundwater.
- Cap dry tailings with impermeable materials.
- Establish permanent wet cover to limit exposure to the atmosphere.
- Mix with paste to backfill mine.
- Pre-treat tailings with buffering compounds to inhibit chemical reactions.

D. Water Treatment

At modern mines, particularly at those extracting sulfide minerals, water treatment systems are employed to ensure that surface and groundwater released from the site meet environmental standards. Such systems may be necessary while the mine is active and after mine closure. A treatment system may be an active system such as a water treatment plant that adds buffering agents to acidic water to increase pH and precipitate metals. Or a treatment system may be passive, such as one that uses a constructed wetland system to treat metal-bearing water.

Treatment plant concerns include:

- Cost to run and maintain.
- Detection and response protocols for any unacceptable water quality that may occur.
- Proper disposal of sludge generated through the treatment process.
- How long a treatment plant may need to run after the mine is closed, to ensure that waste water meets required quality standards.



Water management, large open pit. Example of water management system with a collection pond in which pH is buffered (upper left) before being processed through an active water treatment facility (lower center). At east edge of the Brunswick No. 12 mine complex (see previous map), Bathurst, New Brunswick.

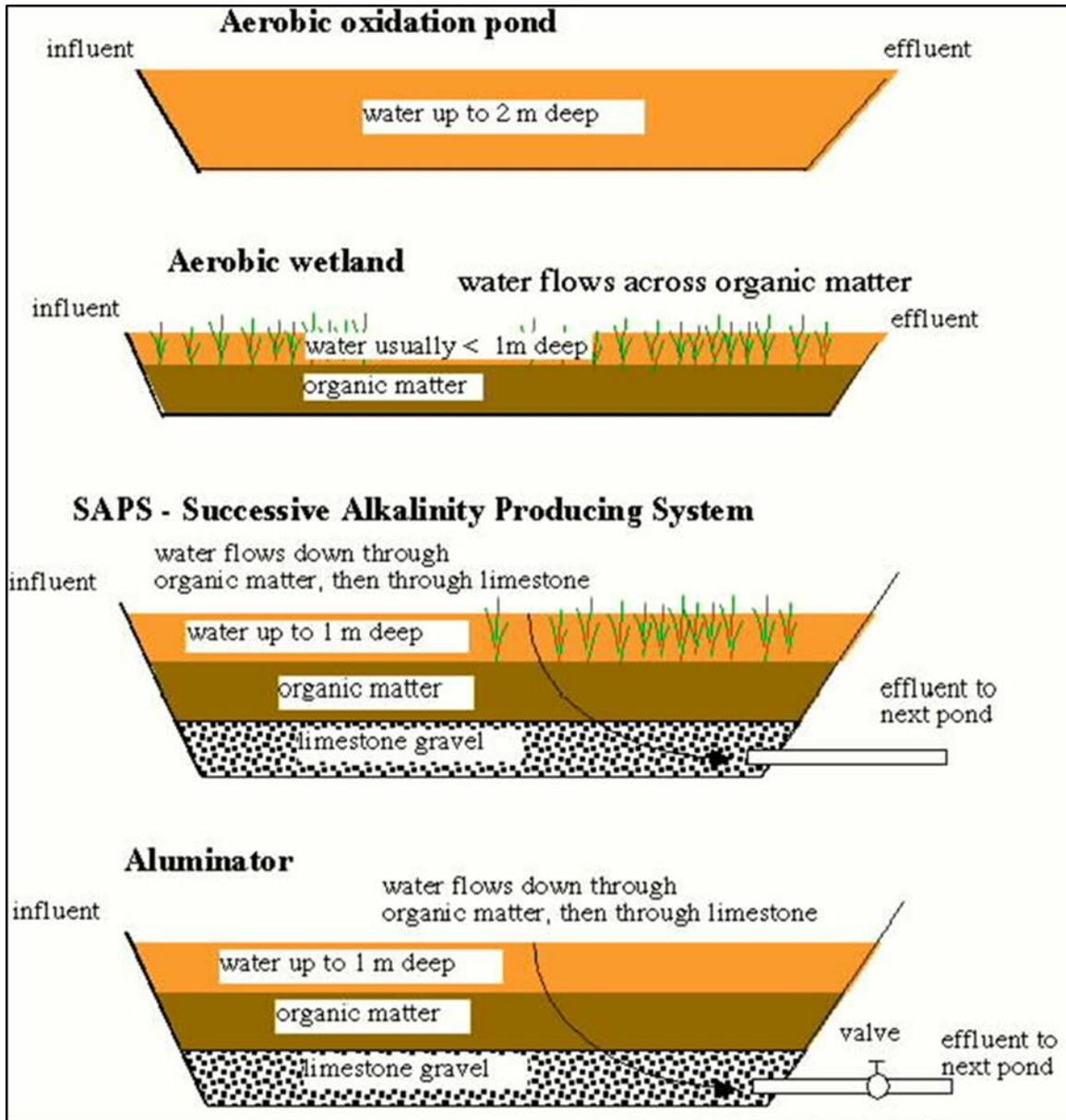
In modern mine construction, mined ore may be stored under cover to limit water exposure, and waste rock may be stored on lined pads so that all water which contacts it may be collected, monitored, tested, and treated before being released to the environment. Management of precipitation and storm water is also an important consideration to minimize the amount of water that comes in contact with mined rock.



Source: Lundin Mining

Water management, modern underground mine. Trucks come to the surface (at 14), and dump coarse ore in enclosed storage area (9). Waste rock is kept in an "environmentally secure," lined storage facility (11), after which it is processed through the backfill plant (13) to be mixed with cement and returned to the underground mine. Ore is trucked off-site to the Humbolt processing facility. Every truck is washed (7) before leaving the site. "Non-contact" water (precipitation) is collected separately and infiltrates at several basins on the property. "Contact" water, including water used in the Truck Wash, is collected in large basins (10), processed through the water treatment plant (6) and returned to the ground through a large infiltration system (4). The surface operations site is about 2300 feet across. (*Eagle Mine, Michigan, which began operations in September, 2014.*)

Passive water treatment. Passive treatment systems may consist of a series of constructed ponds and constructed wetlands designed to alter water that flows through it by gravity, without pumping. Biological processes and layering of materials change the chemistry of water that flows through the passive system. The number of ponds or wetlands and what they do depends on the chemistry of the water flowing in.



Source: Bucknell University/Carl S. Kirby

Passive water treatment. Each pond or constructed wetland in these examples addresses a different aspect of the mine water chemistry. Ponds and wetlands may be employed in series to sequentially adjust the water chemistry.

4. Current and Past Metallic Mining Activity in Maine

While there are numerous metallic mineral deposits known throughout the State, and there has been sporadic exploration activity in the past several years, there are currently no metallic mineral mines in operation today.

The only extraction of earth materials occurring today are rock quarrying and excavation of surficial materials, such as sand and gravel, from pits. Hundreds of these quarries and pits are

regulated by the Maine Department of Environmental Protection under laws and rules separate from those regarding metallic metal mining.

Dozens of small metallic mineral mines, primarily from the late 1800's to early 1900's are scattered across Maine. Among the commodities produced were silver, gold, iron, lead, copper, and zinc, with lesser amounts of nickel, tin, lithium, beryllium, cesium, manganese, sulfur, and graphite.

The Callahan Mine in Brooksville (1968-1972) and the Kerramerican Mine in Blue Hill (1972-1977) are classified as legacy mines, in operation before the Clean Water Act of 1972, and before the Maine DEP was created in 1972. For a brief review of these two sites, see [Legacy Mines in Maine](#) (MGS Circular 15-10, 2015).

5. Legacy Mines vs. Modern Mines

Maine's two largest mine sites, the Callahan Mine and the Kerramerican Mine, are legacy mines. They were planned, permitted, and active before regulations were established to address the environmental impacts of mine development and mine waste. Many legacy mine sites require long-term, expensive environmental remediation (e.g. Brunswick No. 12). Some mines permitted under modern regulations have had significant failures of systems designed to protect the environment. But acceptable standards and requirements have changed over time.

Examples of some differences in best practices between legacy mines and modern mines:

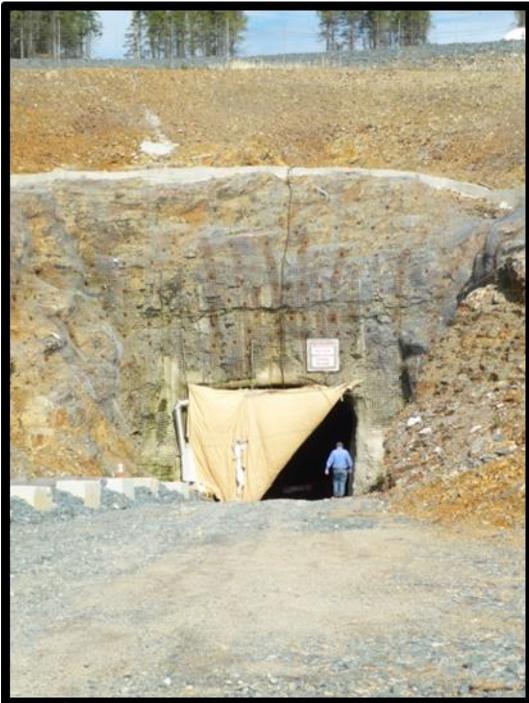
Legacy Mine	Modern Mine
No baseline monitoring before mine construction.	Baseline monitoring of water, air, and biological resources.
Reclamation considered after the mine is closed.	Reclamation considered/tested before mining begins.
Waste rock unsegregated.	Waste rock separated into non-acid generating and acid-generating.
Acid-generating waste rock used for construction around the mine site.	Acid-generating waste rock isolated: back-filled, capped.
Waste rock untreated.	Waste rock chemically tested, interlayered with acid-neutralizing materials.
Tailings dam commonly built from tailings.	Tailings dam built from stable geologic materials.
No liners between mine wastes and the environment.	Liners for waste rock and tailings impoundments.
No water treatment.	Comprehensive water treatment systems.



Photos: Robert Marvinn



Tailings dam at a legacy mine. Left picture looks directly down the slope of the dam, built from tailings, showing significant gulley erosion. Right picture shows the top of the dam structure, with rock armoring along the left and stabilized tailings to the right. (*Brunswick No. 12 mine, New Brunswick.*)



Photos: Robert Marvinn



Waste rock management at a modern mine. Halfmile Mine, New Brunswick, opened in 2012. Entrance to underground mine on left. Pad for potentially acid-generating waste rock on right. Every 1,000 tons of waste rock (about 10,000 cubic feet) is tested for acid-generating potential. Waste rock with a high potential to generate acid will be returned to backfill the mine as mining progresses.

6. Surface Mining vs. Underground Mining

The decision to develop a mineral deposit by open-pit or underground methods depends on many factors, generally related to economics, engineering, environmental impact, and safety. The combination of all these factors and more drives the decision on mining method. Here are some factors and how they might favor each method.

Factor	Open Pit	Underground
Depth of the ore body	Shallow	Deep
Shape of the ore body	Bowl-shaped	Tabular or complicated
Inclination of the ore body	Gentle	Steep
Grade of ore	Low	High
Waste volume	High	Moderate
Production cost	Low	High

7. Mine Reclamation

Modern mines are planned with reclamation in mind. At legacy mine sites in Maine and many around the country, mine reclamation was only considered near the end of active mining if at all. Most U.S. and Canadian jurisdictions now require a comprehensive reclamation plan and funding assurances to be approved at the permitting stage. A typical reclamation includes:

- Stockpiling original soil and overburden to be replaced during reclamation.
- Backfilling the pit or underground excavation.
- Neutralizing acid-generating waste rock.
- Recontouring the ground surface and drainage to approximate pre-mining conditions.
- Establishing native vegetation and wetlands according to intended land use.



Reclamation at a modern sulfide mine. Left: Active pit during operations. Right: Mine site after completion of reclamation in 1999. (*Flambeau Mine, Wisconsin, permitted in 1991.*)

Source: Wisconsin Dept. of Natural Resources